

DARPA Revolutionizing Prosthetics 2009

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DARPA Revolutionizing Prosthetics 2009 Program

▪ Vision

- Produce a fully neurally integrated upper extremity prosthetic with appropriate documentation for clinical trials, FDA approvals, and manufacturing transition.



▪ Mission

- Apply an understanding of the underlying function and control of the human arm and hand when performing the basic functions of reaching, pointing, grasping, and coordinated finger movements to the design of this prosthetic.
- Understand and address the amputees' needs to promote and enhance quality of life issues – comfort, cosmesis, natural control, integrated sensory feedback

This vision enabled APL to rapidly assemble a world-class team of neural scientists, clinicians, technology developers, and commercial organizations for the Revolutionizing Prosthetics program

Restoring function and improving quality of life for our injured warfighters

Modular to suit range of Upper Extremity Patients

Suitable for Range of Injury Levels

(Modular Mechanical Design)

Dexterous control of 22+ degrees of freedom

– mimics natural limb

Natural Control

Natural Performance

Anthropomorphic, speed, dexterity, force

Supports Activities of Daily Living

Sensory Perception of Environment

Pressure, Force

Temperature

Tactile Discrimination

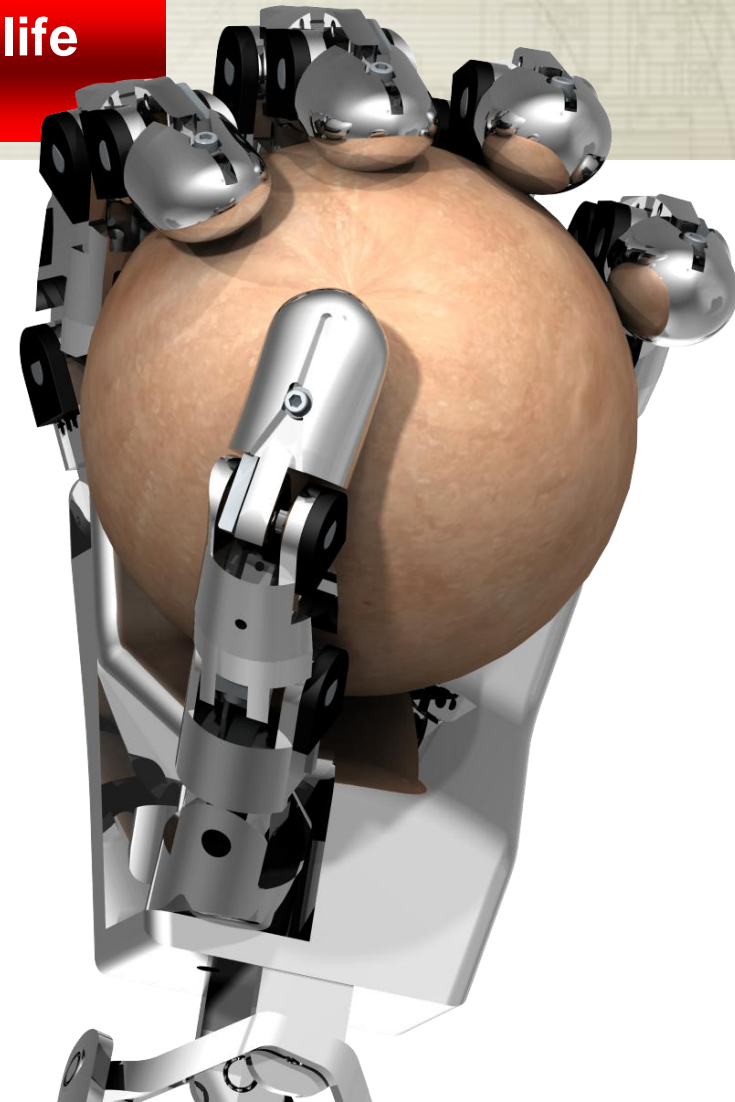
Proprioception

Natural Appearance

Comfortable

Durable, Reliable

Provides Suitable Function at Varying Degrees of Invasiveness



Revolutionizing Prosthetics 2009

Collaborative Partners

> 30 Participating organizations;
4 year, \$70+M program



APL

APL

The Johns Hopkins University
APPLIED PHYSICS LABORATORY

- Program Management
- System Engineering & Integration
- Signal & Image processing
- Virtual Reality & Controls



JHMI

- PI for Medicine
- Human Subjects
- Brain Computer Interface



New World Assoc

- Mechanical Design
- Prototype Development
- Test & Integration



UCI

- Sensory Integration

Otto Bock

- Prosthetic Components
- Control Bus Architecture
- Clinical Support

Otto Bock



Kinea

- Mechanical design
- Controls



Duke

- Intelligent Grasp Control
- Sensory Stimulation



Northwestern

- Non/Low Invasive Strategies
- Enhanced Haptics
- Mechanical Design



RIC

- Virtual Reality Environment
- Targeted Reinnervation
- Patient Needs



USC

- Virtual Reality Environment



U of Rochester

- Cortical Control for Hand Movement



Rutgers Univ

- Peripheral Nerve Interfaces
- Bio-Materials

STANFORD UNIVERSITY



Stanford Univ

- Cortical Signal Extraction
- Signal Analysis & Control

CALTECH



CalTech

- Higher Cortex Signal/Intent Extraction



Orthocare

- SMART socket
- Haptics Patient Interface



UNB

- Neural Integration
- Grasp coding



Utah

- Peripheral Nerve Arrays
- Neural Integration
- Wireless Electronics

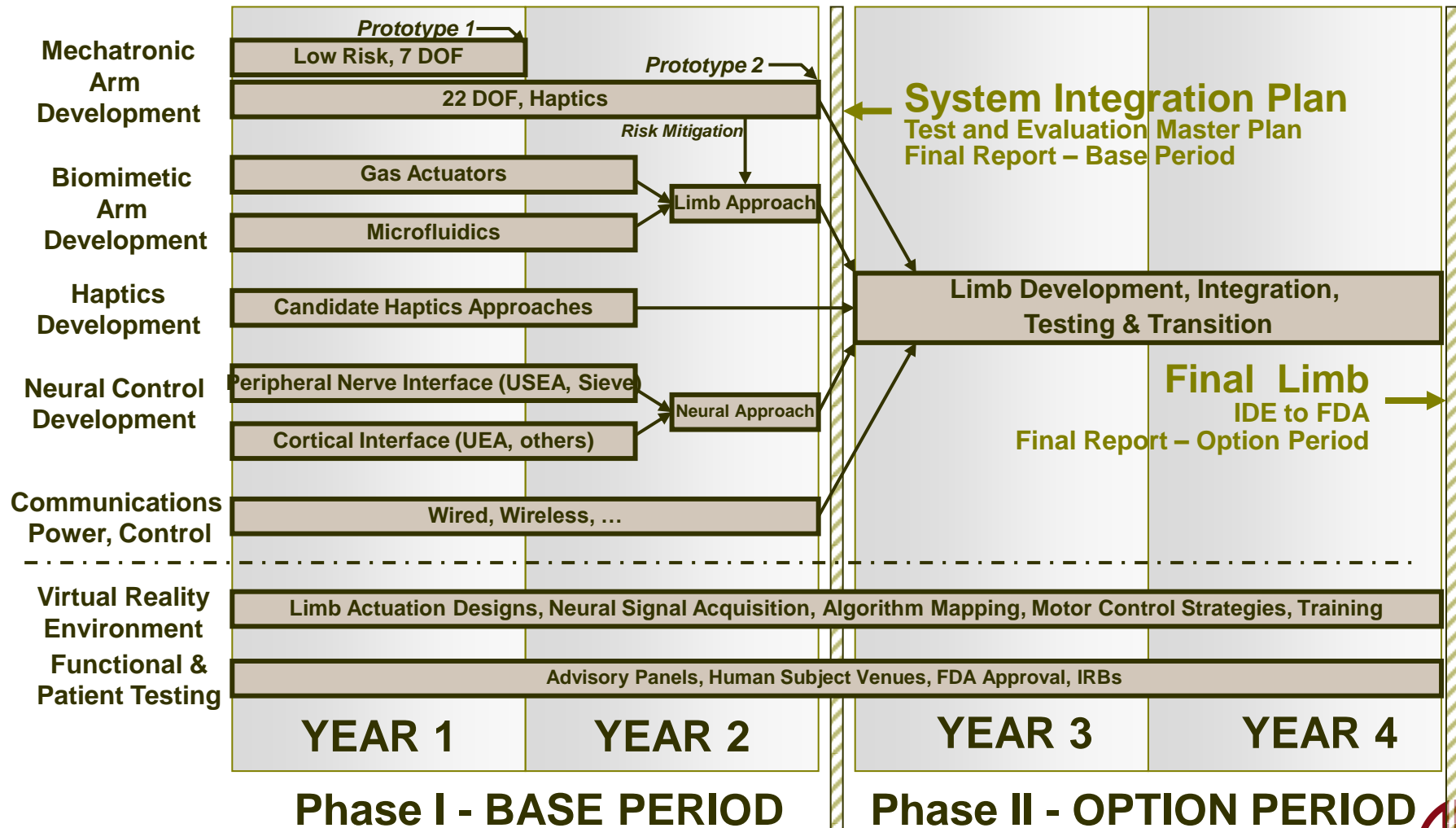


Sigenics

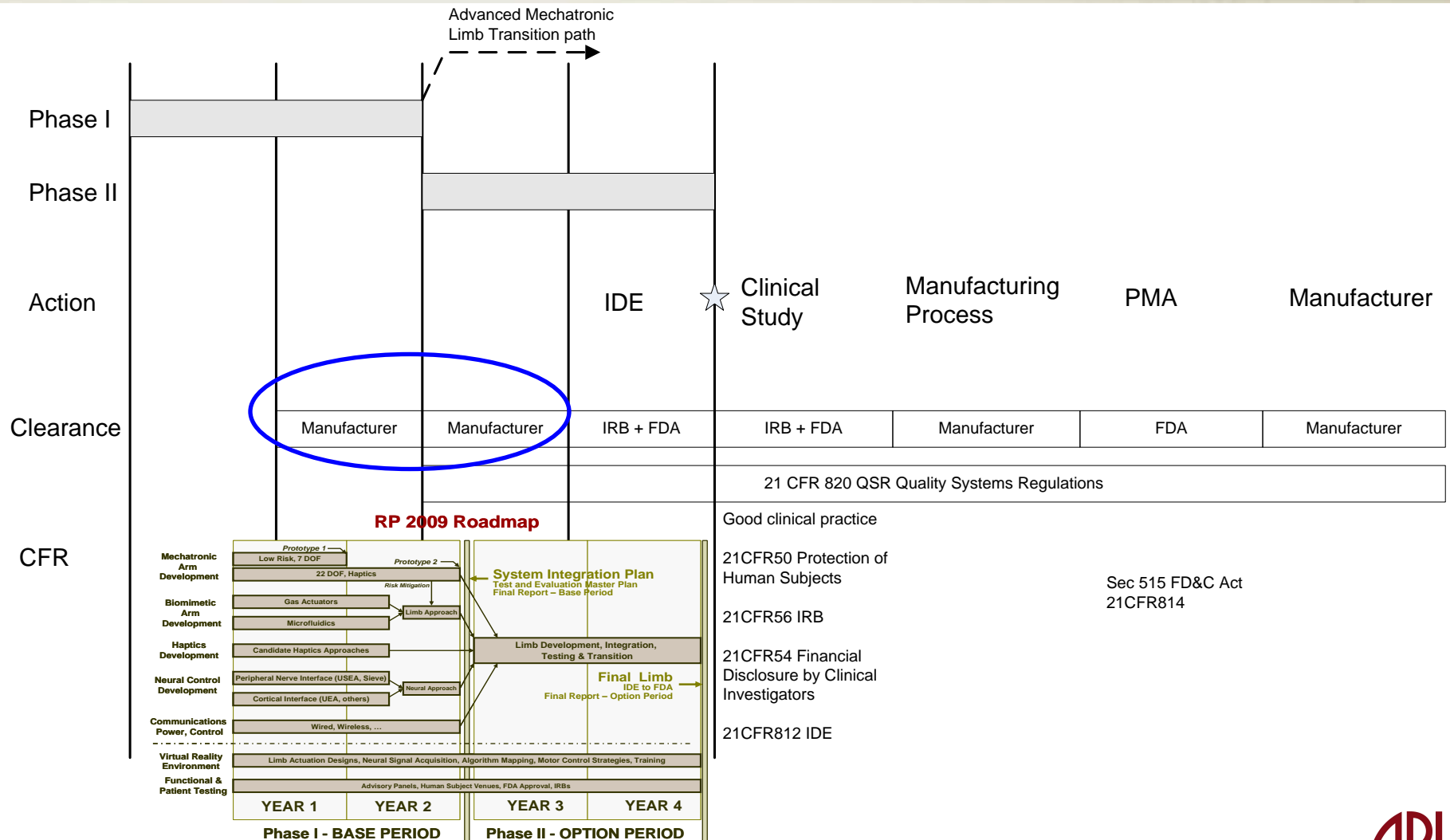
- IMES Implants
- Integrated Electronics

Program Plan

RP 2009 Roadmap

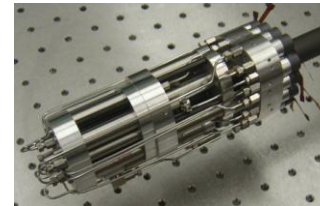
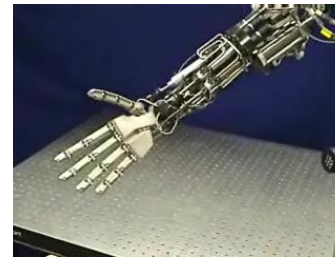
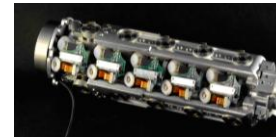
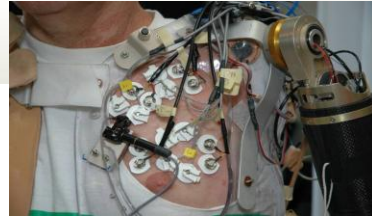


Transition Plan Clarification: R&D through Production

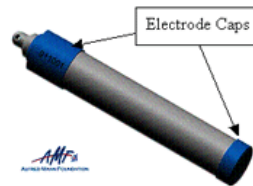
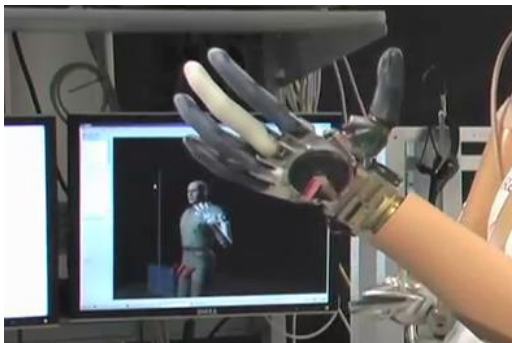


Revolutionizing Prosthetics

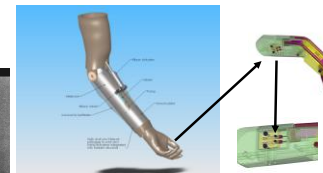
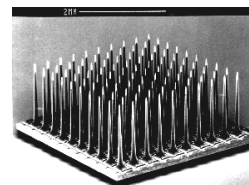
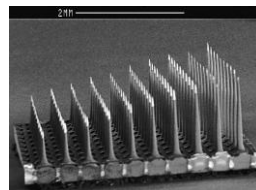
Phase 1 Highlights



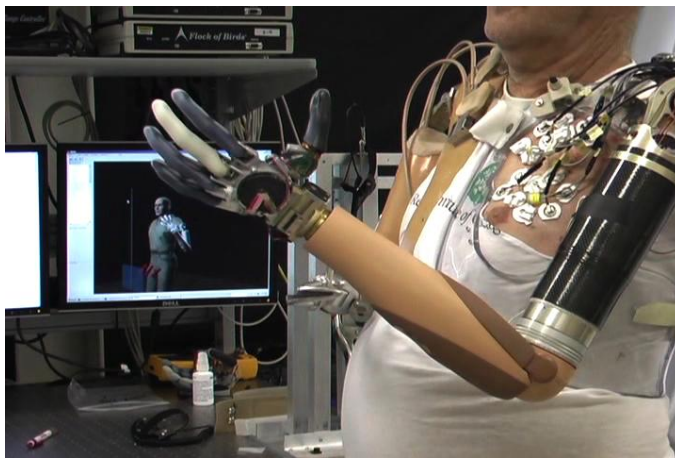
Proto 2 Extrinsic



Alfred E. Mann Foundation RFB BION® Package has IDE FDA approval for use in FES stimulator applications.



Revolutionizing Prosthetics 2009 - Prototype 1



Prototype 1 at RIC – January 2007

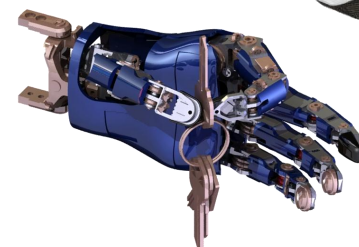
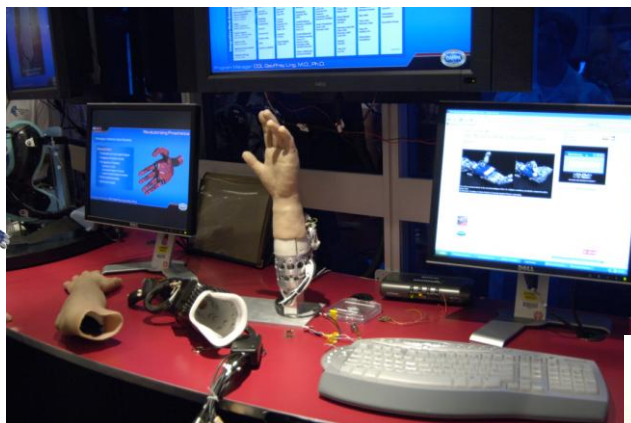
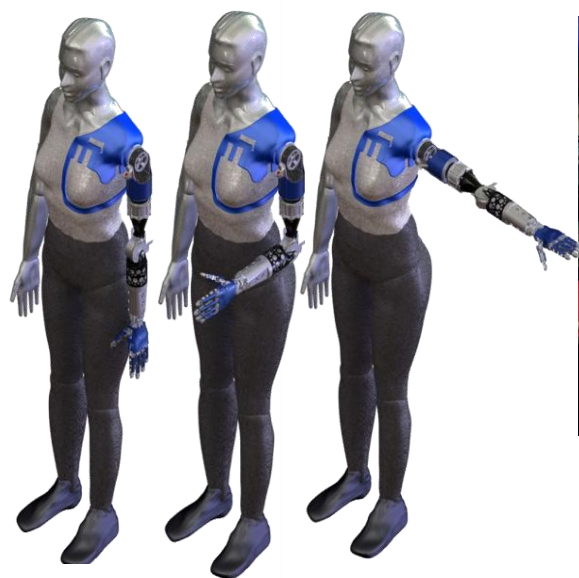
**Prototype 1 Testing
@Rehab Institute of
Chicago**

Jan-Feb 2007

Images Courtesy of RIC Collaboration

Prototype 2 Objectives – Addressing DARPA Requirements Early

- Phase I risk reduction path to final limb
 - Electromechanical actuation
 - All degrees of freedom, speed, torque



- Platform for testing evolving neural control during Phase II
 - Evaluate emerging Control strategies
 - Explore sensory feedback
 - Understand limb design trade-offs for final limb

Proto 2 Arm Architectures

Extrinsically Actuated Hand

18 DOM / 26 DOF



Cobot drives hand, wrist, radial rotator



Extrinsic Hand
11 DOM
21 DOF

Shoulder
2 DOM/F

Humeral
Rotator
1 DOM/F

Elbow
1 DOM/F

Wrist
3 DOM/F

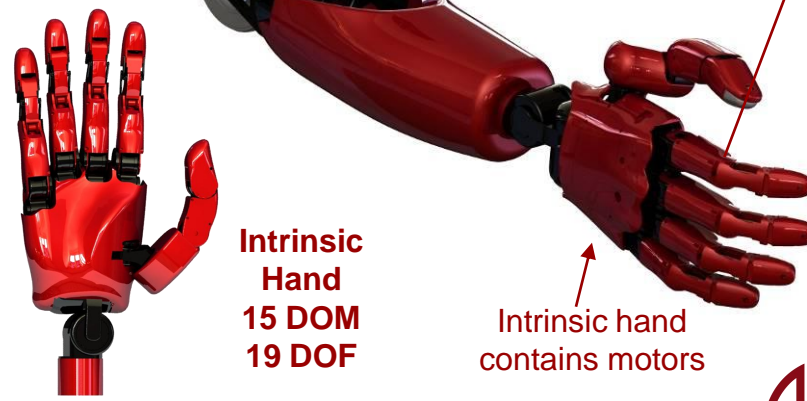
Intrinsically Actuated Hand

21 DOM / 26 DOF

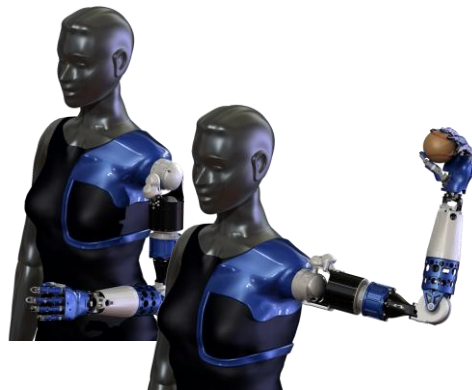


Intrinsic Hand
15 DOM
19 DOF

Intrinsic hand contains motors



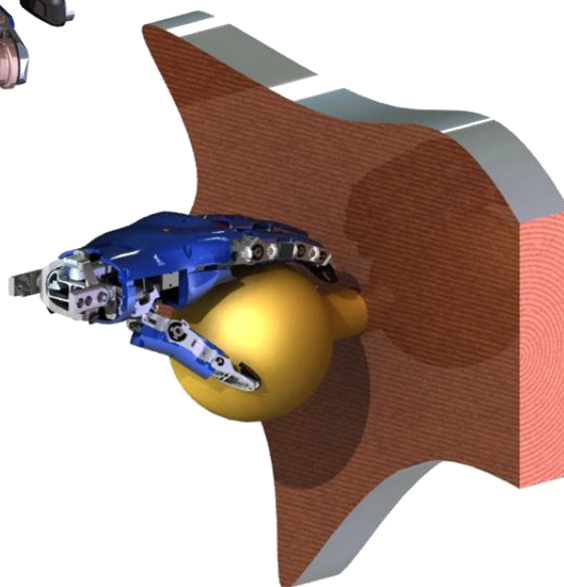
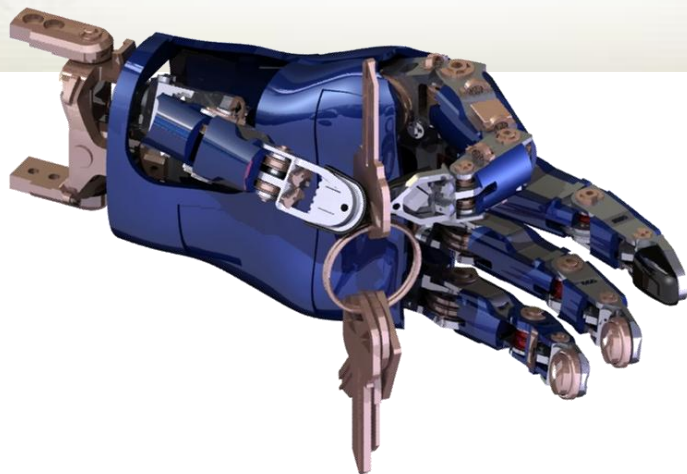
Proto 2 Upper Arm Performance



- Shoulder
 - Flex / Extend
 - Abduct / Adduct
 - Humeral Rotation
 - 45 ft-lbf, 120°/sec
- Elbow
 - Flex / Extend
 - 60 ft-lbf, 120°/sec
- Wrist
 - Flex /Extend
 - Pronate / Supinate
 - Radial / Ulnar Deviation



Hand Grasps



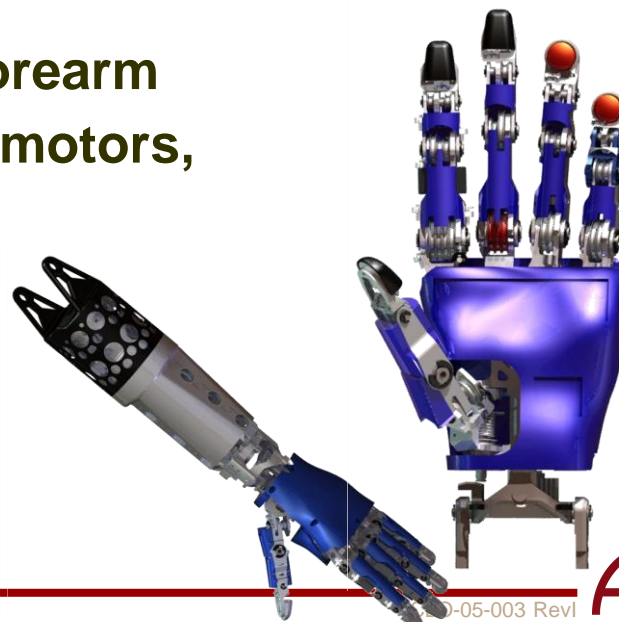
Proto 2 Hands

■ Intrinsic

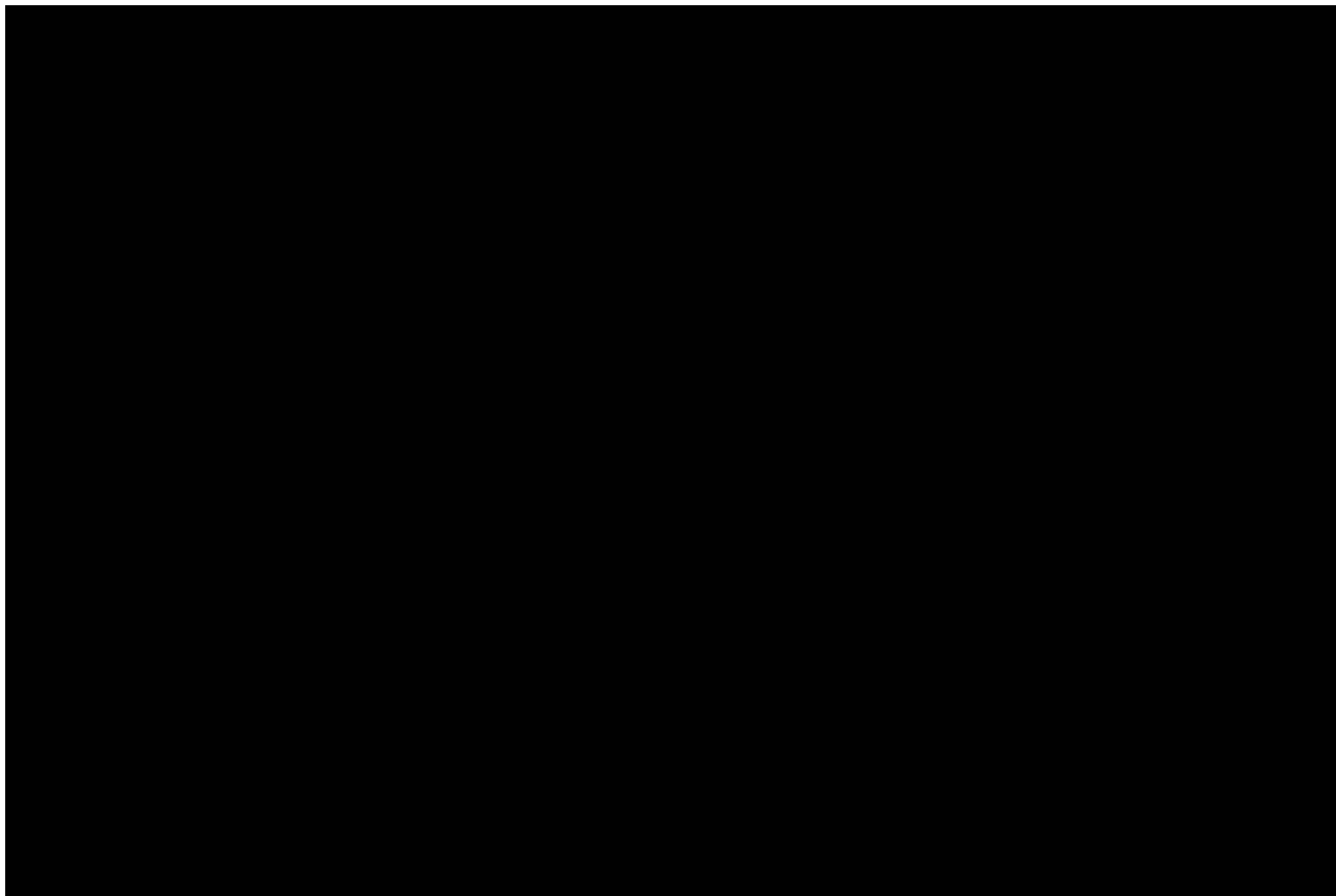
- 15 motors in hand
- 15 actuated degrees of motion
- 4 underactuated degrees of motion
- 19 degrees of freedom

■ Extrinsic

- Motors and transmission (cobot) in forearm
- Cobot: one power motor, 15 steering motors, 15 outputs
- 11 actuated motions with 11 tendons
- 7 underactuated degrees of motion
- 21 degrees of freedom



Prototype 2 Extrinsic Hand Dexterity



Prototype 2 Intrinsic Hand Dexterity



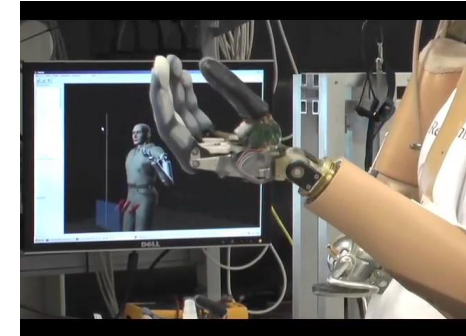
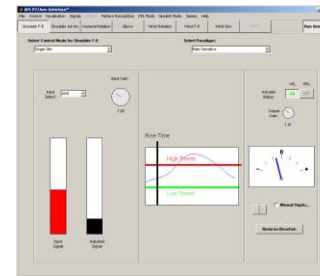
Virtual Integration Environment



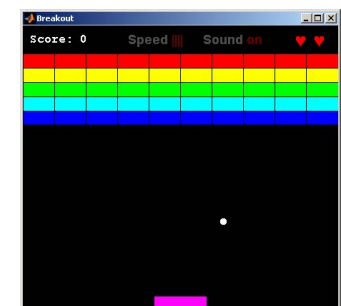
- **Complete limb system simulation environment**
 - Supports engineering development,
 - Neural signal acquisition
 - Algorithm development
 - Mechanical approach evaluation
 - Patient training / therapeutic applications
 - System performance validation and design compliance

- **End-to-end interactive simulation**
 - Acquires control signals (myoelectric, mechanical, neural, other)
 - Signal Analysis: Interprets the intention
 - Controls: Translates intention into movement of a virtual limb
 - Allows the user to interact with objects with feedback (haptics or other)

- **Modular and configurable**
 - Support various limb models and control algorithms
 - Engineering test bed for improvement of these designs
 - Evaluate patient interfaces for control signal extraction and sensory feedback

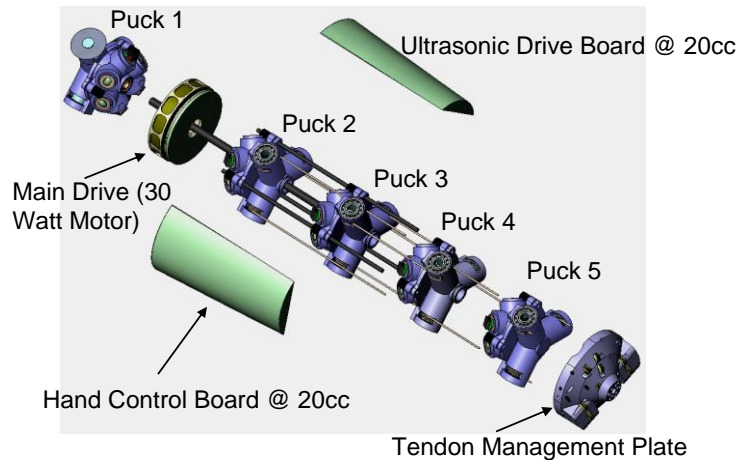


Parameter	Value	Unit	Min	Max	Step
Shoulder Flexion	0.0	rad	-0.35	0.35	0.01
Shoulder Extension	0.0	rad	-0.35	0.35	0.01
Shoulder Rotation	0.0	rad	-0.35	0.35	0.01
Shoulder Abduction	0.0	rad	-0.35	0.35	0.01
Shoulder Adduction	0.0	rad	-0.35	0.35	0.01
Elbow Flexion	0.0	rad	-0.35	0.35	0.01
Elbow Extension	0.0	rad	-0.35	0.35	0.01
Wrist Flexion	0.0	rad	-0.35	0.35	0.01
Wrist Extension	0.0	rad	-0.35	0.35	0.01
Wrist Rotation	0.0	rad	-0.35	0.35	0.01
Wrist Abduction	0.0	rad	-0.35	0.35	0.01
Wrist Adduction	0.0	rad	-0.35	0.35	0.01
Hand Rotation	0.0	rad	-0.35	0.35	0.01
Hand Abduction	0.0	rad	-0.35	0.35	0.01
Hand Adduction	0.0	rad	-0.35	0.35	0.01
Index	0.0	rad	-0.35	0.35	0.01
Middle	0.0	rad	-0.35	0.35	0.01
Ring	0.0	rad	-0.35	0.35	0.01
Pinky	0.0	rad	-0.35	0.35	0.01
Thumb	0.0	rad	-0.35	0.35	0.01
Index 2nd Effort	0.0	rad	-0.35	0.35	0.01
Index 3rd Effort	0.0	rad	-0.35	0.35	0.01

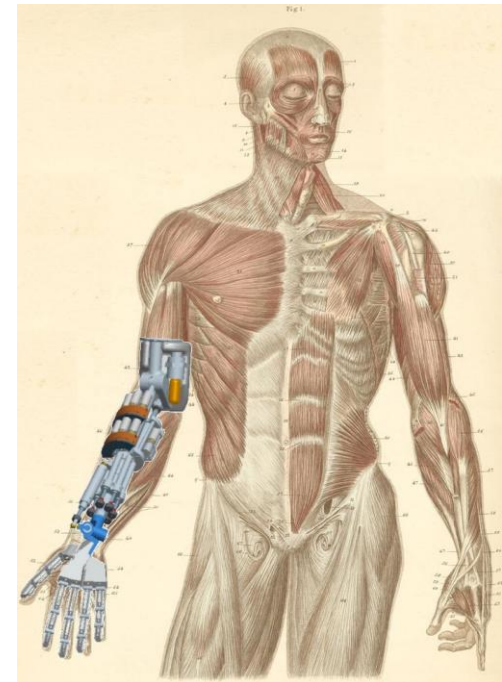


Advanced Actuation

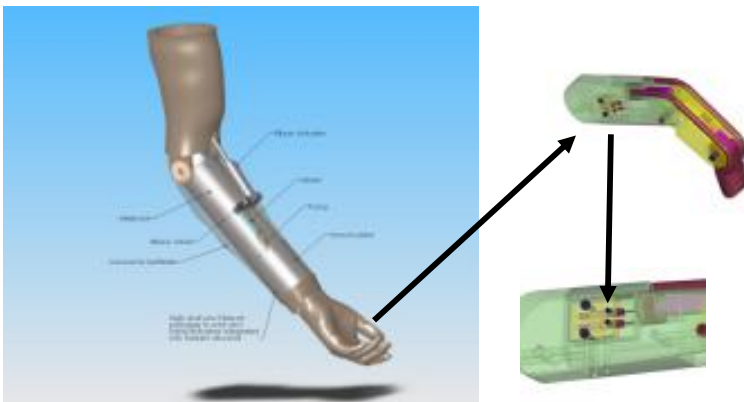
Cobotics



Monopropellant Pneumatics



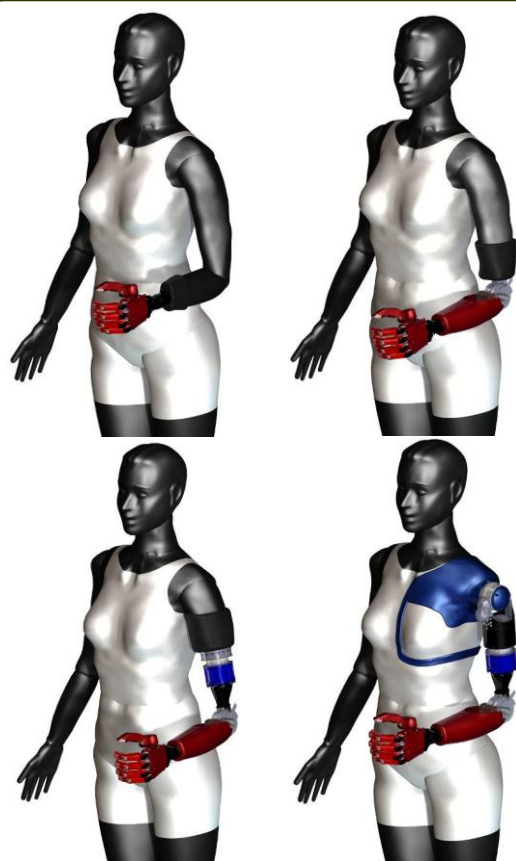
Mesofluidics



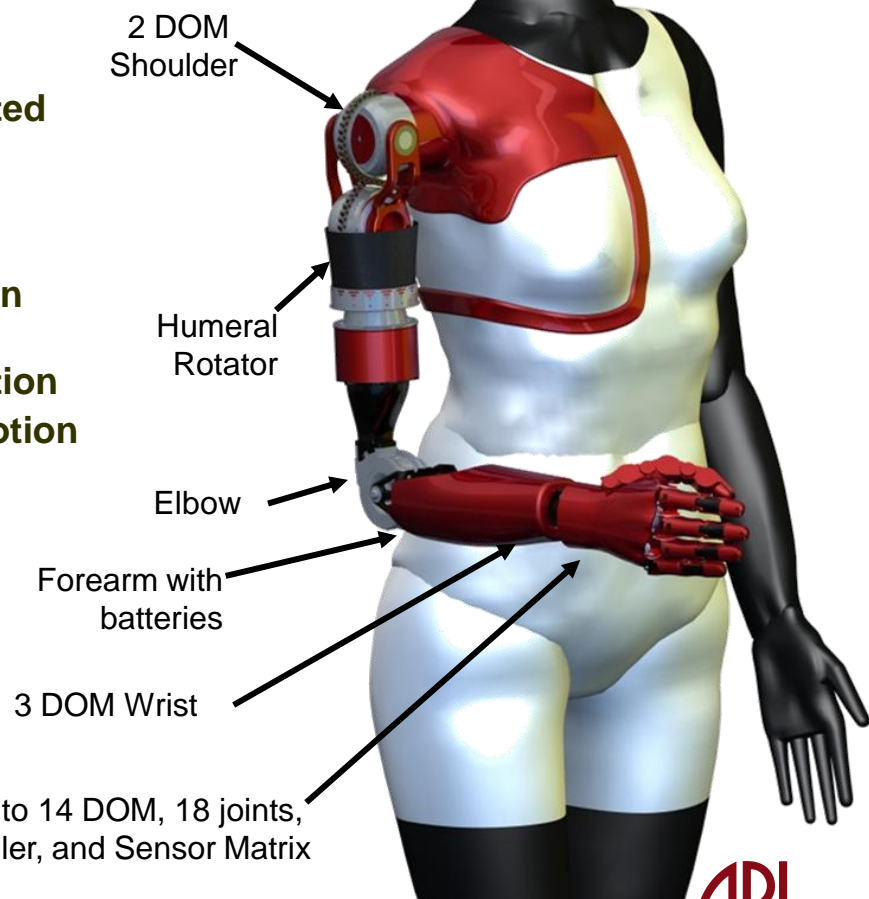
Broader Power Alternatives

Modular Prosthetic Limb Toolkit

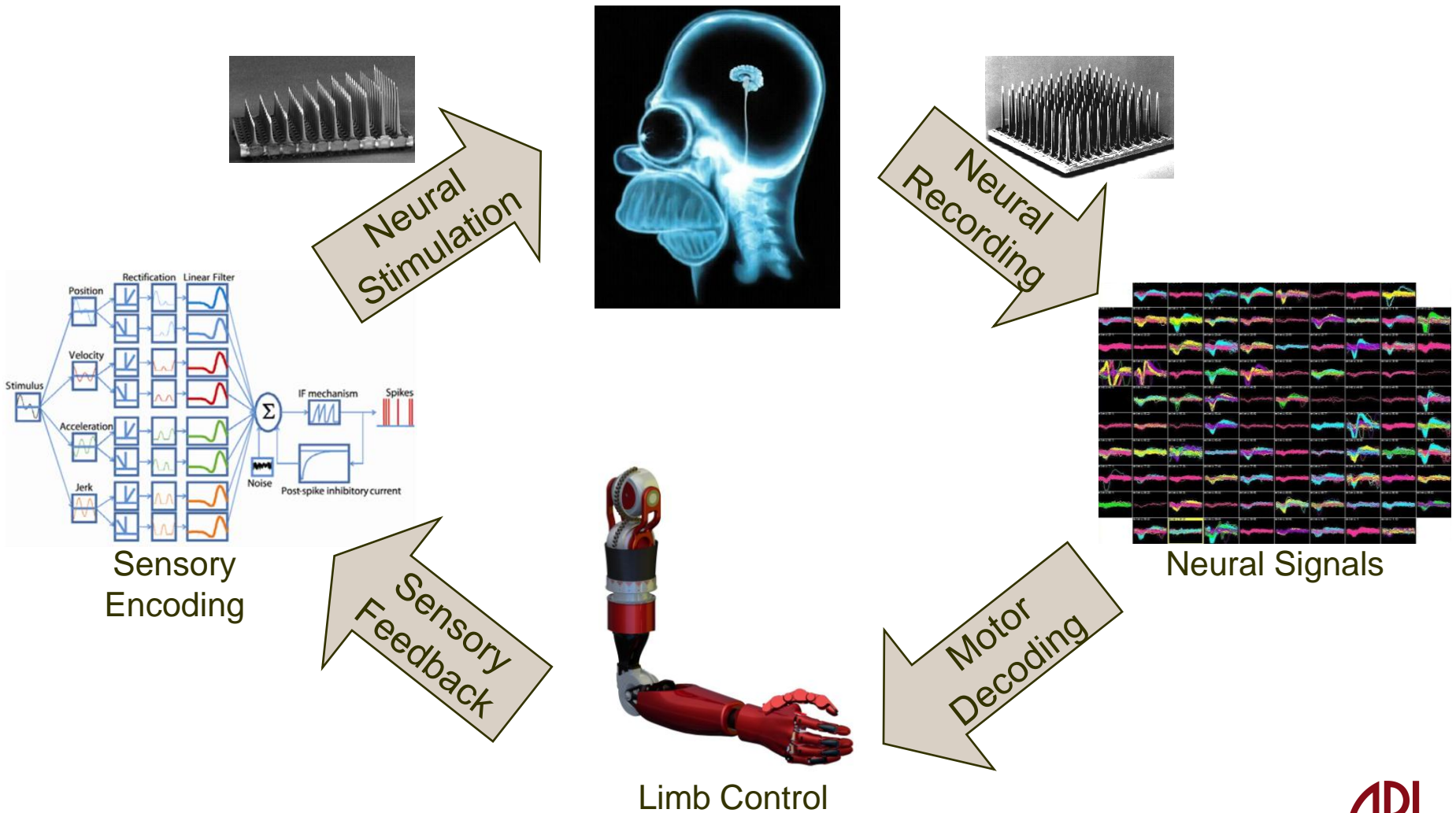
Modular Prosthetic Limb (MPL) modules can be assembled in any combination for use with different amputation levels



- Up to 21 motors
- Intrinsically actuated hand
- Lithium batteries
- Less than 8 lb
- Approaches human strength
- 120 deg/s arm motion
- 360 deg/s hand motion



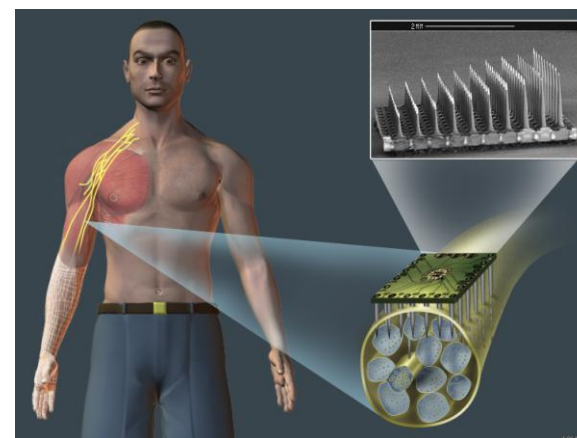
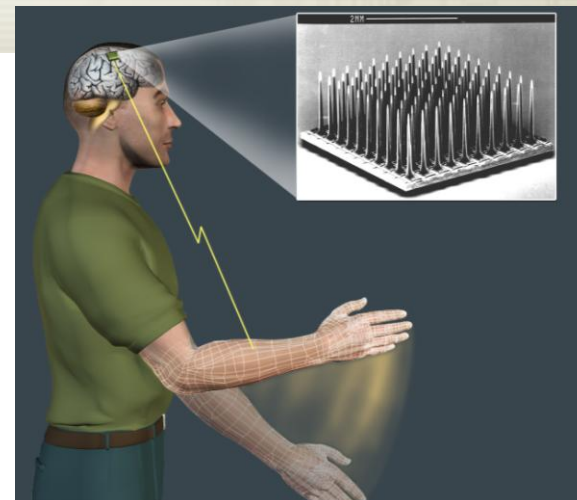
Neural Interface System Block Diagram



Neural Integration

Research Components

Cal Tech	High Level Cortical, Reach Decoding and Prediction
U of Utah	Peripheral Nerve, Efferent and Afferent
ASU	Cortical, Reach and Hand Positioning
USC	Simulation Environment and Biomimetic Control
URMC	Cortical, Dexterous Digit Manipulation
NUPRL/ Sigenics	Wireless Injectable EMG Recording Methods
Zyvex*	Wireless, Direct Peripheral Nerve Interface Methods
RIRC*/UBN	Targeted Motor Reinnervation and Signal Analysis
JHU	Signal Classification, Synthesis, Simulation, and Hybrid Integration



Neural Interface Toolkit

Conventional Prosthetic Control & Non-invasive devices

- Surface EMG (sEMG)
- Tactile sensory stimulator (Tactor)

Minimally-invasive devices

- Implantable MyoElectric Sensor (IMES)

Implantable Peripheral devices

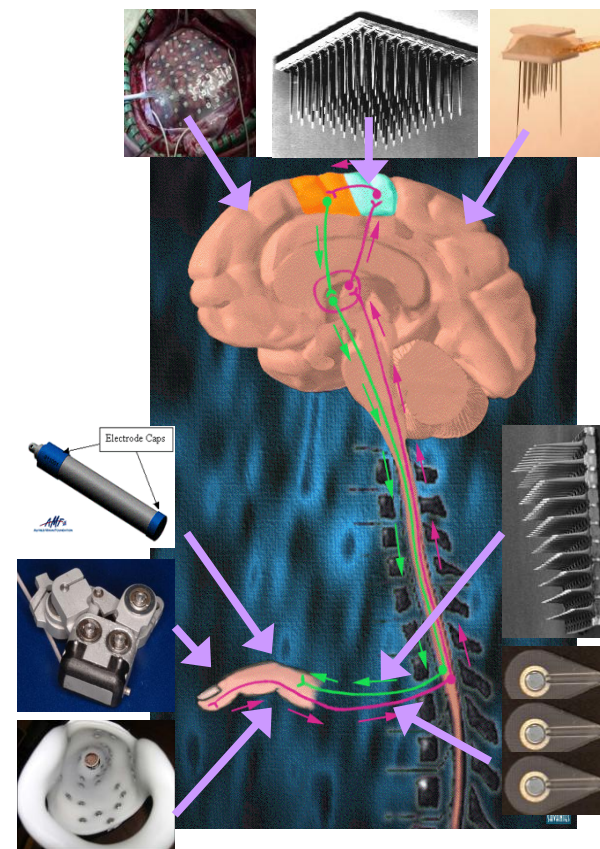
- Utah Slanted Electrode Array for Recording (USEA-R)
- Utah Slanted Electrode Array for Stimulating Feedback (USEA-S)
- Next Generation Peripheral Interface Arrays using Biodegradable Structures

Implantable Cortical devices

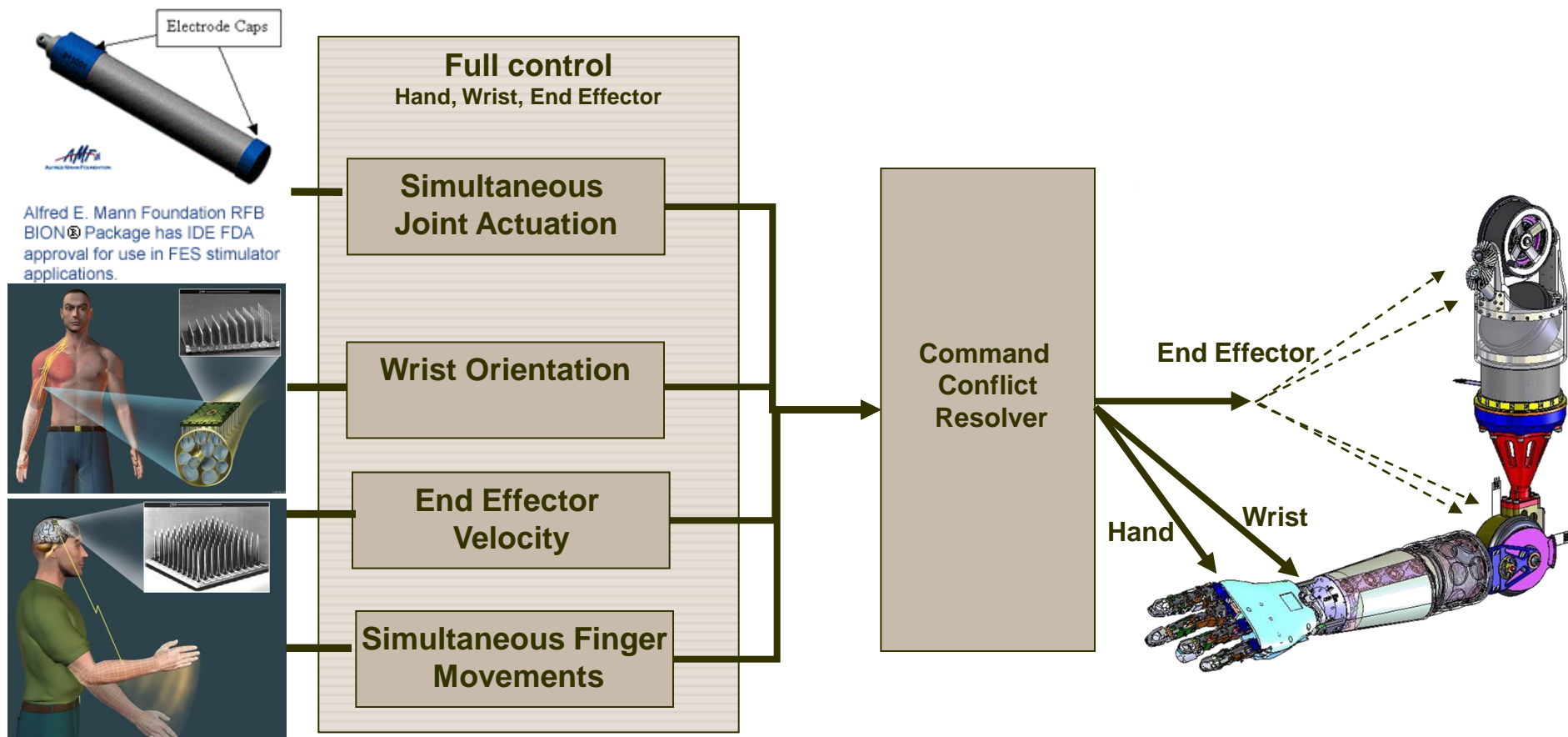
- Epidural electrocorticography grid (ECoG)
- Floating Microelectrode Array (FMA)
- Utah Electrode Array (UEA)

Multimodal System Components (Multi-BID/Multi-PID)

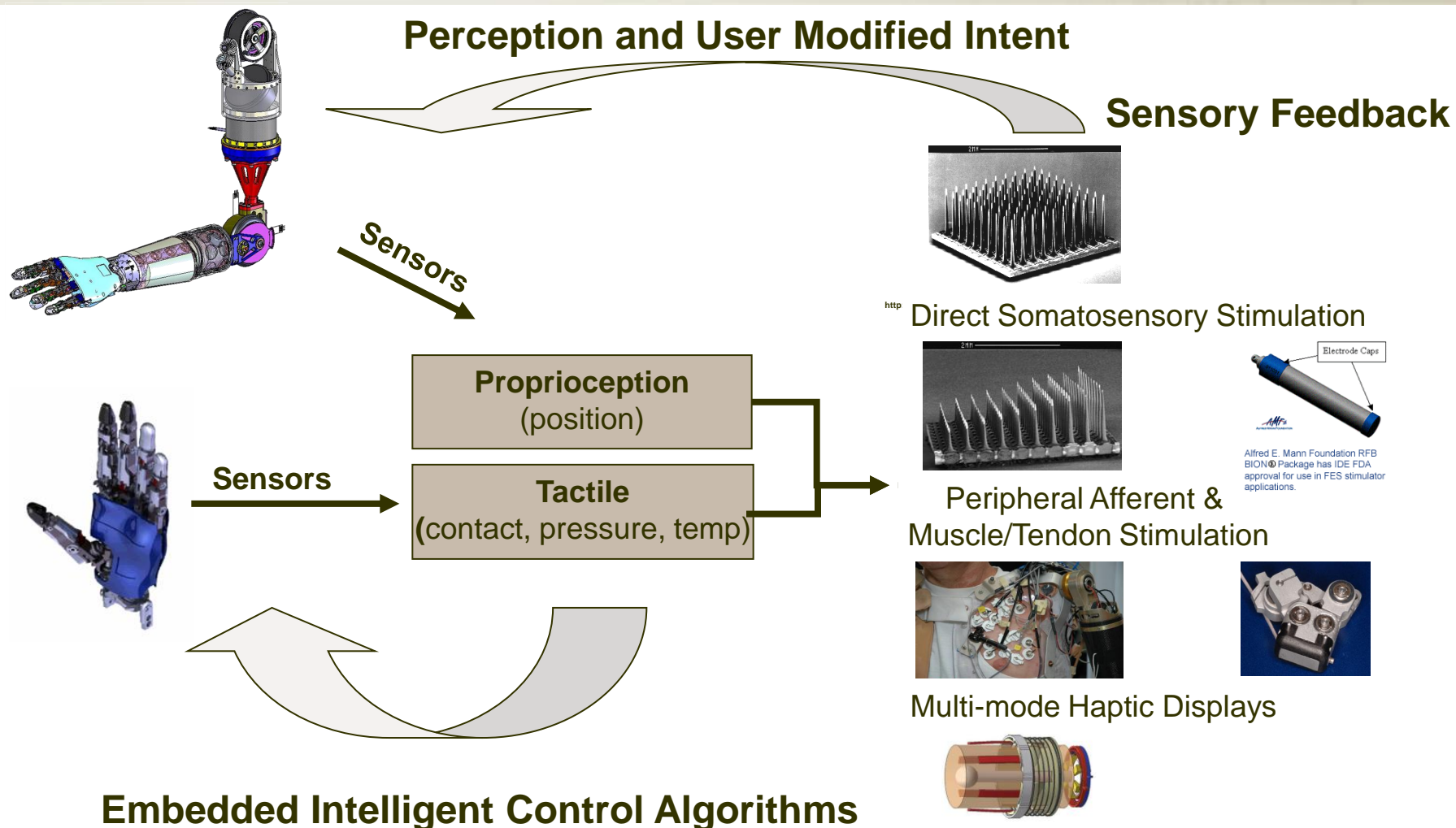
- Multi-Mode Control Unit (MCU)
- Headcap
- Armband



Hybrid Neural Integration Example



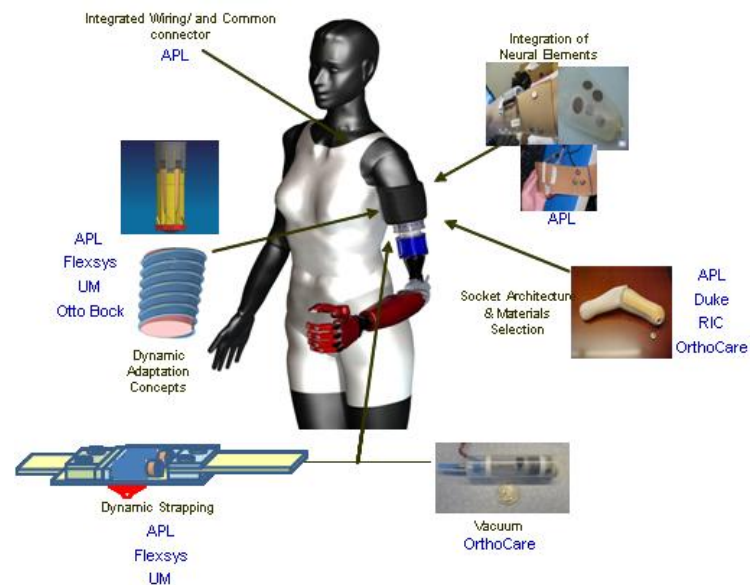
Neural Integration Strategy with Sensory Feedback



Comfort & Appearance

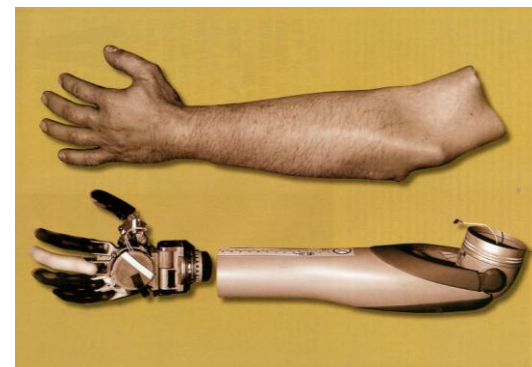
Body Attachment

- Investigating multiple volume accommodating and dynamic shape changing socket methods
 1. Pneumatic or air filled bladders
 2. Hydraulic or fluid filled bladders
 3. Vacuum attachment methods
 4. Electro-active Polymers
 5. Shape changing material structures



Cosmesis

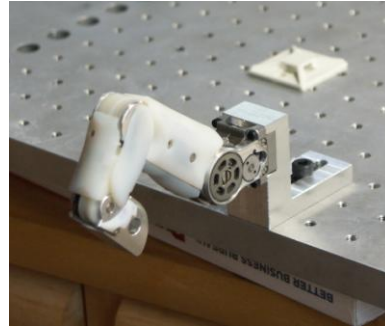
- Exploring alternative materials and designs for reducing stress on joints
- Establishing metamerism insensitive color formula
- Testing for sensor performance (force, vibration, slip, thermal)
- Testing alternative mold designs to improve fabrication



Phase II System Build & Integration



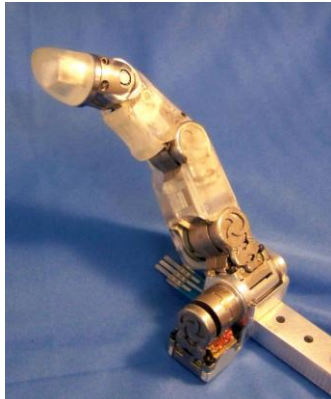
One Motor Finger Subassemblies



One Motor Finger



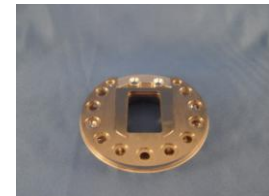
Elbow / Humeral Rotator
Load Testing
(150 lbs)



Thumb



Thumb with Cosmesis

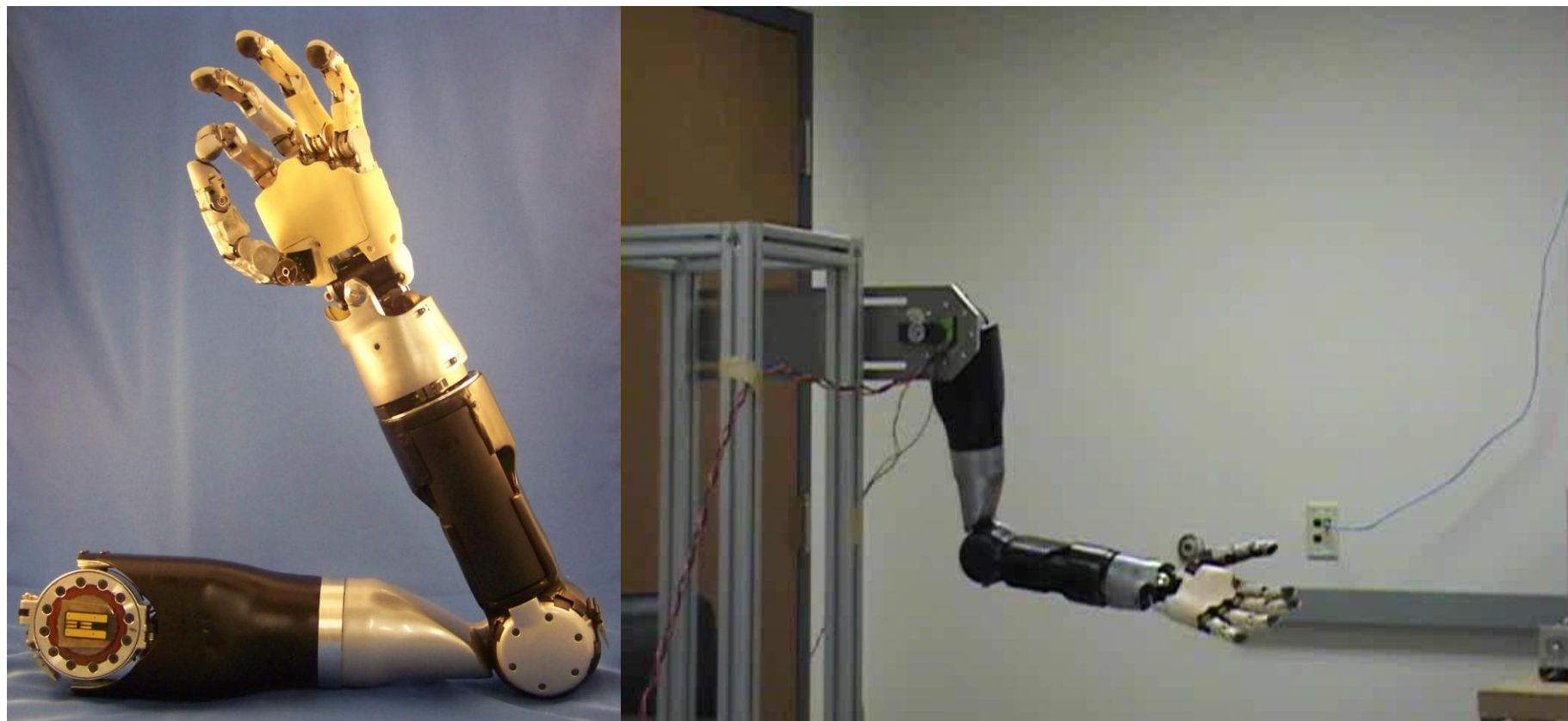


MPL Common Connector



Large Motor Controller

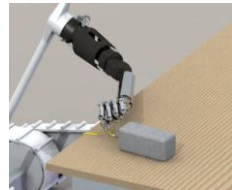
Phase II Modular Limb System



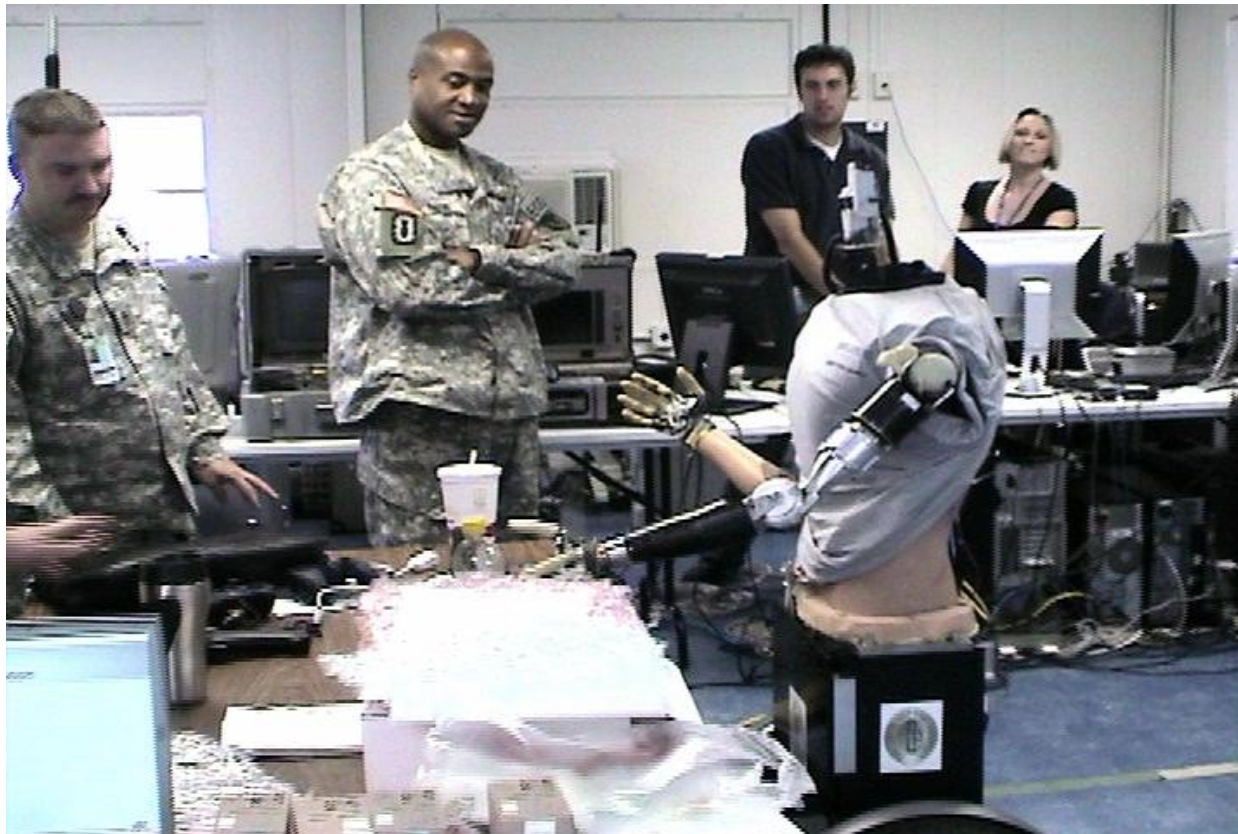
Technology Transition

The Upper Extremity Prosthetics market alone may not have the base to sustain the advanced limb system...

- “Opportunities to scale” – leverage subcomponents of limb/neural systems into additional applications
 - Extend to lower extremity & related rehabilitation applications
 - Military → IED defeat, battlefield trauma care/extraction robotics
 - Homeland Defense → chem/bio response, rad mitigation
 - Medical → peripheral nerve repair, spinal injury mitigation rehabilitation, remote tele-care
 - Space → microgravity mitigation, robotic exploration
 - Commercial → assistive robotics, home care, etc.
 - Other...



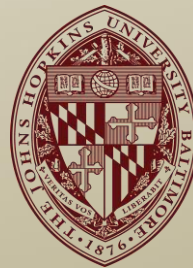
IED Robotics



Thank You!



Questions?



JOHNS HOPKINS
UNIVERSITY

Applied Physics Laboratory